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ECONOMIC EFFECTS OF NOISE ABATEMENT REGULATIONS ON THE HELICOPTER INDUSTRY

by

Alexander Nicholson Conner

December, 1982

Thesis Advisor: M. G. Sovereign

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This thesis discusses the economic effects of noise abatement regulations on the helicopter industry. Increased manufacturing and operating costs from noise abatement regulations on Sikorsky's S-76 helicopter are estimated. The effects on consumer utilization are also discussed. An appendix compares two independent research studies that used weight estimating relationships

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and cost estimating relationships to estimate manufacturing costs of the helicopter by subsystem.

This thesis proposes that if noise abatement regulations are imposed on the helicopter industry without due consideration for future technological improvements, helicopter manufacturers, operators of helicopter businesses, and consumers of helicopter services would be adversely affected.

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Economic Effects of Noise Abatement Regulations on the Helicopter Industry

by

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Lieutenant, United States Navy
B.A., College of William and Mary, 1976

Submitted in partial fulfillment of the
requirements for the degree of

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I. INTRODUCTION

A. HELICOPTER CHARACTERISTICS

Helicopters today are examples of engineering excellence and aerodynamic ingenuity. They have a multitude of unique capabilities that cannot be duplicated by conventional, fixed-wing airplanes. These capabilities are extremely important for the transportation uses to which helicopters are applied. To understand more fully what makes them unique, an understanding of their commercial applications is important.

Aerodynamically, helicopters do not have a stationary wing designed for lift characteristics as do conventional aircraft. Instead, rotating blades produce the required lift that propels the aircraft. Consequently, a helicopter has the capability of decelerating from a cruising speed until reaching a hovering condition. From a hover, a helicopter can move forward or backwards, sideways, up and down. These unique flight characteristics help position a helicopter for precise landings. Helicopters need only a landing area slightly larger than their rotor diameter to ensure proper clearance. This vertical landing and takeoff capability provides greater flexibility in selection of landing zones or heliport locations, especially in congested business districts or on confined oil rig platforms.

The helicopter is also capable of operations on unprepared surfaces. Other aircraft that have vertical takeoff capabilities incorporate high velocity fans or jets that require prepared or heat resistant surfaces. The ability of the helicopter to operate from unprepared surfaces provides an almost limitless choice for landing sites. The ability

to use unprepared surfaces is also an advantage for the helicopter during emergencies. While an airplane needs to find an area that is relatively flat and clear, a helicopter needs only a small clearing.

The most important characteristic of helicopter flight is the helicopter's ability to hover. This is a flight condition in which the aircraft remains motionless over a fixed position. From hovering conditions, helicopters have proven themselves as excellent vehicles for search and rescue.

Helicopters can not only hover, but taxi themselves to any position that is required. By hover-taxiing, an aircraft can position itself away from larger airplanes without disrupting normal flight operations. Often, helicopters use airport landing facilities, but hover-taxi away from and off of major taxi ways. This capability reduces congestion and interference, and offers a more direct service to helicopter users by bypassing crowded gates.

Aerodynamically, airplanes need a continuous flow of air over their fixed wings to provide lift. Otherwise, airplanes will experience an airflow separation from the wing and the wing will stall. Helicopters, on the other hand, can fly and operate effectively in slow flight regimes. Slow flight permits a shorter turning radius, or shorter airport approach patterns. Air traffic controllers can manipulate helicopters in and around larger, more restricted airplanes by adjusting helicopter speeds. Approaches to landings become safer, and helicopter pilots have more time to correct aircraft performances during conditions of poor visibility.

Slow flying is also advantageous for helicopters in agricultural spraying, police patrol or traffic control, where close monitoring of areas is critical.

Rotary wing aircraft are aerodynamically less sensitive to wake vortex and wind shear phenomena. A helicopter's rotors integrate or filter wind changes, thus dampening wind changes that are felt on fixed wing airplanes. Thus, helicopters do not need long approach paths or line up control as do conventional aircraft. In congested areas, shorter approach paths, and approach paths with steep glide angles, (up to 12 degrees for helicopters vice 3 degrees for airplanes) help reduce the noise footprint generated from aircraft. Steeper glide angles and shorter approaches enable helicopters to use patterns that avoid obstructions that otherwise limit fixed wing flight.

Perhaps the most economic capability of the helicopter is its ability to carry external loads, especially into or away from areas that cannot be transversed by ground vehicles. The logging industry employs heavy lift helicopters to remove felled trees faster than could be removed by truck. Other industrial applications employ helicopters to lift heavy and outsized equipment such as antennae and airconditioning units onto roof tops. The external lift capability is a method by which cargo maybe delivered directly to its destination, saving time and money by eliminating intermediate stops and extra people from handling the cargo.

The last characteristic that differentiates helicopters from conventional aircraft is in the variety of landing gear available to helicopters. Where fixed wing aircraft are restricted to wheels, ski, and floation pontoons, smaller helicopters can be equipped with skids that absorb rough terrain and hard landings better. This helps prevent fuselage damage by transmitting structural loading to the skids.

These characteristics have made the helicopter an extremely efficient vehicle for commercial and military operations. Helicopter manufacturers today are engaged in

expensive and complex engineering research to improve these characteristics.

B. HELICOPTER TECHNOLOGY

The helicopter industry is a large, competitive, and highly diversified industry. Currently there are eighteen helicopter manufacturers world-wide, producing forty-seven models. Domestically, the major helicopter manufacturers are: Bell Textron, Boeing Vertol, Sikorsky, and Hughes Aircraft Company. These companies have produced or have in current operation some 10,000 civilian aircraft, mostly in service in the United States and Canada. In 1981, civilian helicopter sales by U.S. manufacturers totalled $.76 billion, representing 1402 airframes. Total U.S. civil aircraft sales (general aviation, air transportation, and rotorcraft) during the same period reached $8 billion, a sales figure spread over 22,878 airframes [Ref. 1: 73].

Civil rotorcraft production for the free world is projected to double by by the year 1990 [Ref. 1: 3]. If this projection holds true, total fleet needs for civilian activity will surpass military helicopter usage, now estimated at 20,000 airframes. The potential growth and development of the helicopter industry by the turn of the century is dependent upon not only the technological developments and electronic advances designed for multi-purpose uses and all-weather capabilities, but increases in performances such as lifting capabilities and speed.

The dollar investment in helicopter technology and development has increased at even faster rates. Up until 1950, helicopter manufacturers had spent collectively $200 million on helicopter engineering. By 1970, that figure had reached $1.6 billion, and by 1979, $2 billion. By 1990, cumulative monetary outlays for domestic helicopter R&D has

been estimated to be $10 billion, an extremely optimistic forecast [Ref. 1: 2].

The dominate civilian rotocraft has been the light, single-engine helicopter. Towards the end of the 1960's, turbine engines started replacing piston driven reciprocating engines. With the introduction of the turbine engine, the helicopter could offer a much greater thrust to weight ratio. The market experienced vigorous growth until the 1973/74 oil price increase, at which time increased operating costs caused many operators to curtail or shutdown operations. Not until 1979 did the helicopter industry rebound, when offshore oil exploration added a new demand.

The 1970's also introduced technology dramatically new and innovative from the 1960's. The newer models were more streamlined, with fuselage designs very similar to airplanes. Many of the newer, medium sized helicopters incorporated retractable landing gear that further reduced drag, increased airspeeds, and saved fuel. Helicopter manufacturers stressed technological advances in blade construction and design to eliminate blade noise and vibration, for greater passenger comfort and reduced metal fatigue. The developments incorporated in today's fleet of modern helicopters have a great influence on performance, safety, and cost. The principal technological developments that have made the helicopter competitive with conventional, fixed wing aircraft are:

1. Aerodynamic - The greatest technological breakthroughs have been in blade and fuselage designs that have reduced drag, increased speeds, reduced vibrations, and increased fuel efficiency.
2. Composite Materials - New composite materials provide for greater flexibility in design and protection. This is especially true in the rotor head and hub assembly, where fewer but stronger materials can replace older and heavier components. Helicopter weights have continued to decrease, and equipped with more powerful engines, offer an airframe that is more productive.

3. Engine Performance - Turbine engines, currently replacing older and less powerful piston engines, are desirable because they are more fuel efficient, reliable, weigh less, and for the same horsepower.

4. Electronics and Avionics - Improvements in the electronics field have affected many systems in helicopters. Improvements in navigation and communication have significantly improved the helicopter's ability to fly at low altitudes accurately, where very high frequency (vhf) and line-of-sight signals transmitted by ground facilities cannot be received. In the near future, all navigation for ships and aircraft will be directed from satellites, increasing the performance of helicopters as they travel extended distances over water or terrain, away from normal means of reception. Pilot workloads will be reduced with the integration of new controls, displays, and computers. Procedures once performed manually, such as calculation of fuel consumption or center of gravity loadings, will be automatically calculated. Computers will help free the pilot from non-flight related duties. Consequently, pilots can spend their time more efficiently by paying closer attention to aircraft performance and procedures. Computers will not only aid the pilot in monitoring aircraft performance, but instantly provide valuable data concerning weather, dangerous wind shears, or obstructions to flight. Through the use of computers, instantaneous and accurate data can be retrieved and analysed, and precautions taken to ensure the safe conduct of helicopter operations.

5. Reliability and Safety - Helicopters today are designed by manufacturers to be as safe as possible. Modern cockpits house comfortable seats with better visibility and simiplified controls. Back-up systems to replace failed components of major systems are standard on many corporate and commercial models. Passenger comfort and safety have been improved with better sound proofing and reduced vibration. The cost per seat mile for helicopter flights is being lowered as more people fly in helicopters and helicopter efficiency increases. Today, helicopters are competing for more air routes by offering a broader application of transportation needs.

Helicopters are able to fly in almost all conditions of inclement weather, except icing and severe turbulence. The helicopter can achieve this, and at speeds competitive with fixed wing aircraft of the same weight and size. Because the helicopter has the capability of landing at heliports located closer to commercial areas, the time saved by using helicopters is a competitive tradeoff to the faster speeds of conventional aircraft. Helicopters today, given medium range capability and passenger loading, can maintain cruise speeds at 150 mph, with increases in performances being demonstrated by newer derivative aircraft every day.

Future rotorcraft technology does not differ greatly from current, conventional designs. Large helicopters will eventually accomodate a hundred or more passengers and service air routes at medium distances of 100-300 miles, directly competing with fixed wing carriers in high density locations [Ref. 1: IV-1].

Smaller to medium size helicopters may see aerodynamic changes with the elimination of the tail rotor as an anti-torque device. New techniques are being tested that not only eliminate this tail rotor, but increase helicopter speeds substantially.

The Tilt Rotor is such a new class of helicopter. The Tilt Rotor aircraft will position its rotors to various overhead and forward positions, depending on the desired aircraft attitude. Higher speeds will be obtained without sacrificing the vertical takeoff and landing characteristics of a conventional helicopter.

The X-Wing rotorcraft is another helicopter variant, intended for high speeds without sacrificing vertical take-offs and landings. The name is derived from the shape of the wing, which when viewed from directly overhead and when it is not spinning, forms an "X". Once the aircraft is airborne, the spinning X-Wing will be locked into place and function as an airfoil for forward flight.

A third innovative airframe currently being tested is the ABC concept, or Advanced Blade Concept. It is designed very similarly to a conventional helicopter, except that instead of one rotor attached to the main mast, there are two. The two rotors counterrotate around the mast, effectively neutralizing the stalling property a blade encounters when rotating to the trailing side of the rotational path. The ABC concept is designed to have an advancing blade on both sides of the aircraft, with the stalling blades on the trailing sides feathered to reduce drag. Another advantage

of the coaxial rotor system is that a tail rotor is not required to compensate for main rotor torque. The ABC is capable of speeds comparable to fixed wing aircraft, at altitudes in excess of 24,000 feet, and still perform take-offs and landings vertically. Prototype ABC aircraft have been test flown by military and NASA pilots, but the aircraft is still in its experimental stage.

The future of rotorcraft development is not only designed around flights at faster speeds and higher altitudes. New design features also stress applications towards heavy lift helicopters, with gross weights exceeding 300,000 pounds. The commercial applications of heavy lift helicopters are many and varied, but the key to heavy lift development is the propulsion components, (engines, drive trains and rotors) and their influence on helicopter performance.

These new derivatives are the next generation of vertical takeoff and landing (VTOL) aircraft. With continued urban development and the high costs of airport construction and location, helicopters will play an ever increasing role in commuter and medium range transportaion.

C. COMMERCIAL APPLICATION AND MARKETS

Commercially, rotorcraft production is one of the fastest growing sectors in sales and production in the aviation industry world-wide. By 1990, civil rotorcraft production is expected to exceed $3 billion per year, or 17% of all civil aviation production [Ref. 1: 70]. From 1960 through 1970, civilian helicopter production output doubled, and is expected to double again in the 1980's. By 1990, over 20% of all dollar expenditures for aircraft purchases will be for helicopter or VTOL aircraft. This growth, for the most part, has been spurred by technical breakthroughs mentioned in the previous sections.

Bell Textron Corporation has dominated helicopter production since the 1960's, and still maintains itself as a market leader. Other domestic manufacturers that share in helicopter production are the Boeing-Vertol Company, Hughes Aircraft, and Sikorsky. These domestic producers actively compete for foreign markets with overseas consortiums such as Westland-English, Aerospatiale-French, and Agusta-Italian. In these countries, the rotorcraft industry is heavily subsidized through government procurement, and aircraft models are tailored to meet commercial and military applications. U.S. manufacturers, on the other hand, are able to meet expanding and profitable market demands by designing and producing various models of helicopters to meet the requirements demanded by the different users. The European manufacturers produce a highly competitive and efficient aircraft, but on a magnitude one-tenth that of U.S. production.

The helicopter of today performs a number of diverse and important missions. As a vehicle for public service, the helicopter has been employed as an ambulance to reduce transit times from accident sites to hospitals. Helicopters are also used for public safety, such as traffic control and rescue missions. Helicopters are constantly being called upon for transportation during periods of natural disasters and relief.

The helicopter is also used by private corporations to transport technitions, support equipment, and personnel to and from offshore oil rigs and drilling platforms. As oil companies expand their exploration further and further offshore, there will be an increased demand for helicopters to meet longer flight times and heavier payloads. Helicopters have successfully withstood extreme temperature variations, from North Sea oil exploration to Persian Gulf operations. In the Gulf of Mexico today, there are 847

helicopters supporting 137 mobile drilling rigs, 992 multiwell production platforms, and 117 more under construction [Ref. 1: 55].

Petroleum Helicopter Incorporated, (PHI) flys over 1000 flight hours per day from its fleet of 400 helicopters to oil rigs in the North Atlantic, South America, the Gulf of Mexico, and Africa. More time and money is saved by oil companies using helicopters for personnel transfers than when slower surface vessels are employed. Steady growth in this market can be seen with the ever increasing demands for energy.

Forestry, logging, and agricultural spraying are other diverse and useful applications for helicopters. Helicopters are capable of penetrating terrain too remote or rough for land vehicles or conventional aircraft. Helos can also be refueled from trucks driven to the periphery of unprepared fields, eliminating transit times to and from airports. This means that the helicopter is able to remain onstation longer periods of time, economically covering more area in shorter periods of time, and maximizing aircraft usage.

The economic uses of helicopter applications are numerous. Transportation of large, outsized cargo or of commuters for intercity service is being handled more efficiently today by rotary wing aircraft. Helicopters are not cheap to maintain and operate, and like other high performance machines, must be maintained and inspected often. In the long run, operating costs and maintenance costs far exceed the acquisition costs. The helicopter is designed around a complex mechanism of interrelated dynamic components, some working in harmony, and others in opposition to each other. These components must meet high tolerances for speed, temperatures, and durability. As helicopter technology advances with industry demand, more efficient components will be developed.

Unfortunately for the U.S. helicopter industry, an environmental noise regulation that is being drafted by the FAA could hinder future growth and sales in this market. New regulations designed to limit helicopter noises are being considered. The industry feels that noise regulations will slow helicopter growth. The industry is working with the FAA to identify methods to record helicopter noises and establish noise limits that do not jeapordize the growth in helicopter sales. The next chapter will introduce the FAA's current position on noise abatement, and the industry's position towards these issues.

II. NOISE ABATEMENT IN THE AIRCRAFT INDUSTRY

A. FAA REGULATION OF THE AIRCRAFT INDUSTRY ON NOISE ABATEMENT

In 1968, the FAA was first charged by public law number 90-411 (later in 1972 with public law number 95-574) to regulate aircraft design and equipment for noise reduction purposes. This was known as the Noise Control Act of 1972, and the FAA prescribed standards for the measurement, control, and abatement of aircraft noise. In essence, the mandate by Congress to the FAA was designed to promote an environment that would be free of noise that jeopardized the health and welfare of citizens.

To establish accurate criteria and noise levels for the aircraft industry at that time, the FAA worked in close connection with the Secretary of Transportation and the Environmental Protection Agency. Their object was to ensure that regulations placed on the industry would be realistic and obtainable. It is important to note that during this early time period, 1968-72, Congressional direction focused primarily on the larger and more noisy fixed-wing aircraft. Little attention was paid to the helicopter industry and its noise generating problems, mainly because helicopters were largely being operated in areas away from urban development.

The FAA first set about to develop an acoustical technology that could be used to measure aircraft noise during different flight regimes. This measured data then had to be quantified and determinations made as to what types of noises were dangerous, from what areas of the aircraft were the noises generated, and the expected costs associated with reducing the noise levels. The aircraft industry was very

large at that time, and the FAA, NASA, and industry engineers spent more than $200 million to improve the noise characteristics of commercial and private aircraft. Interestingly, over 50% of this amount was subsidized by the U.S. government for the industry's research and development efforts [Ref. 2: 6-1]. The research required to find and implement more effective noise control technology was extremely expensive. Unlike the rotary wing industry, where noises are generated through a number of aircraft components, the noises generated from fixed wing aircraft were primarily generated from their powerful jet engines. Developing technology that would surpress engine noises alone would bring fixed wing aircraft within FAA prescribed limits.

In contrast to fixed wing research and development funding, funding for helicopter noise reduction technology has been extremely small [Ref. 2: 6-2]. This is inconsistent with the helicopter's complex noise problem and was overlooked for years partly because there were no experts in helicopter acoustic technology. These shortcomings left the industry ill prepared for noise abatement rules as imposed on the commercial airlines and the private industry. The FAA found that regulating helicopter noises would be much more complex. As will be explained later, the FAA and helicopter manufacturers set about to work together to establish noise rules that were, for helicopter manufacturers, economically reasonable and technologically practicable.

As a regulatory agency, the FAA had insufficient data to establish guidelines for helicopter noise abatement rules. In 1975, the FAA proceeded with the development of noise certification regulations. During the next four years, the FAA and the helicopter industry held a series of eleven meetings. In these meetings, each side tried to learn the others' concerns and arrive at some mutual resolution. The

meetings were also designed to improve the FAA's data base on helicopter noise. Unfortunately, the information that was generated from these meeting was of limited value in establishing a set of standards because of each manufacturer's varying techniques of data accumulation and correlation.

In 1978, the FAA entered a rulemaking cycle which culminated in 1979 with its proposed helicopter noise certification standards, entitled: Notice of Proposed Rule Making (NPRM) number 79-13. The industry immediately set about to evaluate the proposals. In January of 1980, the helicopter industry responded with a detailed and extensive summary of the economic and developmental impact of the NPRM. In effect, the industry replied that the FAA's regulations as setforth in NPRM 79-13 were highly restrictive and, if the proposed rules were to be enforced by law, would require manufacturers to invest heavily in research and new technology.

From January 1980 until the fall of that year, the FAA did not respond to the industry's claims. In an attempt to bring the FAA closer to the industry's needs, the ICAO Committee on Aircraft Noise, Working Group B, (CAN/WG/B) recommended to the FAA a set of proposals that hopefully would bring closer together the requirements of the FAA with the technological skills and desires of the industry. The CAN/WG/B also recommended that the FAA delay implementation of the rule until more data could be accumulated and evaluated.

The CAN/WG/B's recommendations proposed to the FAA did open a negotiating door between industry and government. It was now clear to industry, comprised of the thirteen major helicopter and engine manufacturers, that they should attempt to provide more complete economic data on just how severely the helicopter industry would be affected by noise

rules imposed by the FAA. The FAA in turn wanted as complete a study as possible for proper rule making. This thesis will evaluate the economic cost considerations affecting one manufacturer, Sikorsky, and the production of its medium sized, commercial helicopter, the S-76. In this report, cost constraints to manufacturers and operators of the S-76 will be evaluated under conditions of noise regulations.

The S-76 is Sikorsky's newest helicopter for the commercial and industrial markets. It is a highly competitive and advanced helicopter, designed for operation well into the 21st century. If the FAA imposes strict noise requirements on the helicopter industry, Sikorsky will be faced with major redesign problems and expensive retooling costs. In an attempt to estimate the costs to Sikorsky with its production of the S-76, and the effects these costs will have on market sales, a careful analysis of major S-76 aircraft components and their costs will be made. A relationship exists between aircraft component weight and manufacturing costs, and this relationship will be studied to estimate what additional costs would be incurred by Sikorsky if forced to redesign the S-76.

B. SOURCES OF HELICOPTER NOISE

As mentioned earlier, helicopter acoustic technology is considerably more complex than that of fixed wing aircraft. The interactions of various noise generating areas makes noise abatement rules difficult to quantify and regulate. Unlike a conventional airplane that produces noise through its power plants, the helicopter generates tonal signatures from areas other than its engines. Areas of the helicopter that are major producers of noise are:

1. The Main Rotor. The main rotors are the most significant contributors to helicopter noise. The main

rotors act as lifting surfaces, and produce a periodic and random flapping and slapping noise as blades compensate for variations in loads and stresses. Design features are now being tested to decrease this noise, such as reducing rotor radii, expanding the blades' chord, changing the number of blades, altering blade tip design, and varying rotor speeds. These modifications involve long periods of development, since improvements must be evaluated against helicopter performance and life cycle costing.

2. The Tail Rotor. Like the main rotor of conventionally styled helicopters, the tail rotors are substantial generators of noise, but of a different pitch and quality. The tail rotor rotates much faster than the main rotors, producing a higher and narrower band of tones. The tail rotor interacts with disturbed airflows from the main rotor, further disturbing and increasing the generation of noise. The tail rotor is connected to the main transmission through a series of gears and reduction assemblies that produce a high pitched, whinning resolution.

3. Transmission Area. Helicopters incorporate various gear boxes and transmission systems that direct power from the engines to the rotor blades. These transmission systems have their own gearing ratios that produce different harmonics, usually of a very high pitch. These high pitch tones are extremely damaging to unprotected ears, especially to people who operate around helicopters for extended periods of time without protection devices.

4. Power Plants. The turbine engines used on today's helicopters produce various compressor tones and exhust noises. The more powerful the engine, the noiser the helicopter will be. Surpressing engine noise alone will eliminate only one area of helicopter noise. As can be seen, there is an interrelationship of many components, dynamically in opposition to each other, and operating at critical tolerances. The problem of quieting helicopter noises is technically a very difficult one.

These noises have been a major consideration to the helicopter industry, primarily as helicopters begin commuter services to urban areas. By nature, the helicopter is a low flyer and therefore closer to the audible range of people. Heliports have traditionally been located closer to downtown areas and closer to where people live and conduct business. The tradeoff, paradoxically, is that the helicopter is fulfilling a more efficient service by bringing commuters closer to business centers, while at the same time, annoying those people who have to work nearby.

Through comparative test studies, it has been found that the noise footprint of a helicopter during approach, landing, takeoff and departure, is considerably less intense than that of most airplanes. Helicopter noise is limited to a smaller region than that of an airplane, for two primary reasons. First, the helicopter is smaller than the larger airplanes and secondly, a helicopter's approach and departure flight path is steeper [Ref. 3: IV-15].

Helicopter noise signatures are comparable to other loud noises generated through normal everyday traffic found in metropolitan cities. Sound levels are measured in decibels, relative to a sound pressure level that is being used as a reference. The annoyance of a sound is caused by the sound pressure and tonal qualities, duration, and rapidity. The ear is considerably more sensitive to sounds centered around a frequency of 1000 cycles per second than sounds of equivalent pressures but of a lower frequency. Tonal qualities also affect sound annoyance, like the whinning of pure tones emitted from tail rotors. A wide band of noise of equivalent pressure centered around a pure tone may not be uncomfortable. What is uncomfortable and annoying is the duration of the noise and the rapid rise in sound pressures instead of gradual rises.

One of the areas of greatest concern for the FAA and the helicopter industry was agreeing upon a standard for helicopter noise measurement. For vehicle noise emission, an Effective Perceived Noise (EPNdB) was used. It provided a measure of certain characteristics of noise, namely the presence of tones and duration. A major drawback to using EPNdB as a measurement, was that EPNdB instruments are extremely expensive, costing upwards to $5000. A cheaper alternative, but less accurate, was a noise level measuring scale that corrects noise levels for daytime/nighttime noise events (LDn). The LDn scale is more environmentally

oriented, and takes noises that are emitted, and corrects them for 1) the number of noises and 2) the times the noises occurred [Ref. 2: 1-1].

Despite the high cost of measuring noise using EPNdB criteria, the FAA and the helicopter industry selected this measurement as their standard for noise review. The LDn was selected as an environmental response standard, a derivative of dB(A) measurements used by communities for many years to measure vehicular noises. Consequently, a mix of two measuring standards will be used by the FAA when they conduct their noise testing and evaluation on helicopters.

Quantifying noises by the use of electronic data gathering machines is the scientific and more technical approach. The subjective approach to measuring noise and annoyances is not easy to quantify, but the subjective attributes cannot be overlooked when considering noise standards. Examples of subjective attributes are:

1. How do people feel about the necessity and/or preventability of noises? People may feel hostile if their concerns for noise abatement are being ignored.
2. Are people aware of the importance and value of helicopter activity, particularly as helicopters perform public services related to saving lives? As the public becomes more aware of helicopter importance, this fact could relieve the apprehension about helicopter noise.
3. The activity and/or time of day that an individual hears a noise is also important. An individual is more easily disturbed or annoyed if the noise is generated at night, or during periods outside of normal daily routines.
4. There is a strong apprehension associated with helicopter noise. Many people are fearful of helicopter noises because helicopters fly lower to the ground and produce sounds unlike other vehicles. Helicopters have been associated with search and rescue services, and this causes anxiety and fear among civilians.

The flight profiles the FAA and the industry used to measure helicopter noises were regular helicopter flight regimes. Testing was conducted during takeoffs, fly overs, and approach sequences, and analysed according to aircraft

catagories. There are six helicopter classifications, based primarily on seating capacity, number, type and horsepower of engines used, and acquisition costs. The six classifications are:

Category 1. 2 to 5 seats; 150 to 300 hp; piston single engine

Category 2. 5 to 7 seats; 350 to 550 hp; turbine single engine (light)

Category 3. 6 to 14 seats; 800 to 3000 hp; turbine single engine (heavy)

Category 4. 6 to 14 seats; 800 to 1300 hp; turbine twin engine (light)

Category 5. 15 to 28 seats; 2500 to 3200 hp; turbine twin engine (medium)

Category 6. more than 40 seats; more than 4000 hp; turbine twin engine (heavy)

Within these six catagories fall all civilian helicopters. The S-76 helicopter is a catagory four aircraft, with a seating capacity of fourteen people and equipped with two engines. The flight profiles measured by the FAA are recorded from three microphones, located on level ground in a straight line and arranged perpendicular to the flight path. The distance between each microphone is 150 meters, and the helicopters are flown over the center microphone during each of the required flight profiles. The noise generated by the helicopters is picked up by the microphones, and processed electronically to provide a noise level in EPNdB and dB(A). The data is then graphed by frequency and amplitude against time, and corrected to filter out other noises or deviations from non-flight related interferences. This recording technique has been

determined by the FAA and the industry to be the best and most accurate method for recording helicopters during the three flight regimes.

C. ERTP REGULATIONS

The helicopter industry recognizes that the FAA is charged by Congress to regulate helicopter noise. In carrying out this mandate, the FAA is limited to a degree in design and implementation of regulations because they are required to consider 1) all relevant data 2) ascertain that the proposals are economically reasonable and technologically practicable and 3) include the public in rulemaking activities [Ref. 2: 2-1]. The helicopter industry is trying to protect itself by supplying as much pertinent economic and technological data to the FAA to justify its position that helicopter technology is already at a very high state of development. If strict noise abatement regulations are to be imposed, the cost to manufacturers to redesign and produce quieter helicopters would be restrictive. In response to the FAA, the industry has proposed major recommendations that the FAA review before it drafts noise rules.

The industry has recommended that the FAA establish an interim limit that is three EPNdB above the limits already proposed. This new limit would be phased in over a ten year time period for new production, new design, and derivative aircraft. The industry has also proposed that certain aircraft be excluded from noise rules, such as helicopters employed in agriculture, fire fighting, external load carrying operations, and remote area operations [Ref. 2: 7-1]. The industry feels that aircraft used in these capacities take them outside populated areas where noises would be an annoyance. Helicopters involved in these missions are usually more powerful and thus more noisy. Imposing noise

rules on these helicopters would not only be impractical, but could impose an additional cost to operators that would preclude them from using helicopter services.

These recommendations by the industry were considered essential if helicopter production and technology were to keep pace with commercial demand. Consequently, economically reasonable and technologically practicable became a standard of measurement that had to be developed and applied to all helicopters affected by a noise rule. A projection of over $2.2 billion in helicopter demand has been forecasted by the industry by the year 2000, and an improper or premature regulatory rule could have devastating affects on the market.

Many helicopters now in production do not meet the FAA's proposed regulations. Technologically, tomorrow's helicopters will be designed around faster speeds and heavier payloads. NPRM 79-13 does not allow for acoustic growth as helicopter speeds increase. A rule that does not compensate for faster speeds or increases in gross weight could impact future growth.

The phrase, "Economically Reasonable and Technologically Practicable" must be carefully interpreted and satisfactory for each party before any noise regulation can be meaningful. If there is disagreement on the interpretation as set forth by the FAA, then there will be continuing disagreement on behalf of the industry.

The industry feels that a regulation that satisfies ERTP should establish a noise limit for future, newly designed airframes. These noise levels should be based on current, commercially successful models, and at the same time not penalize manufacturers for uncertainties in future designs. A regulation that satisfies ERTP should not limit manufacturers from developing more productive models for the future.

The difficulty in establishing these requirements is that sufficient economic and technical analyses have not been performed. Noise levels of current generation helicopters first have to be conducted before ERTP requirements can be defined. Once analyses on current helicopters have been completed, the information will help establish guidelines from which all helicopters may be evaluated. Regulations that are based on incomplete or insufficient data run a high risk of doing economic harm to the industry.

The term derivative helicopter has been mentioned previously, and should be more accurately defined. Derivative models are those that are developed using common technology and designs of prior, usually highly successful models. Derivatives are designated by alphabetical nomenclature, such as model H-1E, H-1L, and H-1N. The further down the alphabet, the more current the model. The ERTP recommendations mentioned above relate to current helicopters only. The industry feels that new designs and derivative helicopters must also have ERTP analyses. If current ERTP regulations set noise limits so low as to "absorb all of the available technology", manufacturers face a difficult situation in planning for derivative models.

There is a necessity among the helicopter manufacturers to be able to accurately predict the noise levels of new design and derivative helicopters. If a regulation noise limit is set too low, while at the same time technology for noise improvement has not been found, helicopter manufacturers will have an extremely difficult time meeting certification standards for their new production models. As a result, new designs and derivative aircraft production might have to be delayed until acoustic technology can catch up to the standards as setforth by the rules. It is very important that noise rules be established that are compatable with 1) the accuracy of helicopter acoustic design,

2) uncertainties found in certification testing, and 3) a growth in allowable noise for derivative helicopters.

Figure 2.1 graphically represents the FAA's proposed noise limits for helicopters, plotted against helicopter gross weight. The chart was taken from the Helicopter Manufacturer's Economic Impact Assessment of FAA Proposed Helicopter Certification Noise Rules, (NPRM 79-13) of December, 1980. The limit lines establish a benchmark from which variations in helicopter noises can be measured. The limits are constant at 85, 86, and 87 EPNdB for helicopters with gross weights below 1764 pounds. The limits are also constant at 105, 106, and 107 EPNdB for gross weights above 176,400 pounds. The limits were joined by a straight-line variation when plotted against gross weight on a logarithmic scale [Ref. 2: 8.1-1].

The FAA has proposed that a helicopter may have a recorded noise level that exceeds one or even two of its benchmarks limits and still pass. However, the noise level for any single flight condition may not exceed a limit by more than two dB. Additionally, the FAA has stated that the sum of noise levels for any two conditions by a helicopter cannot be more than three dB greater than its limit. Overall, the average of the noise levels for the three flight conditions must be equal to or below the average of the limits as established in the FAA's formula in Figure 2.1. The noise limits for the S-76 aircraft have been computed using the FAA's formula and a gross weight of 10,300 pounds. As can be seen, the noise levels for the three flight regimes fall along the FAA's straight line for noise limits.

Helicopter derivatives generally increase in noise with increases in gross weight. NPRM 79-13 allows for a three dB growth per doubling of gross weight, which is considerably less than the acoustic signatures recorded by the helicopter

industry in recent testing. As gross weight doubled on some models whose noise was equal to the limit, their dB signatures increased by as much as ten dB. The FAA had developed its three dB growth margin using aircraft weight as the major parameter, when in actuality, helicopter noise tends to follow disc loading and rotor diameter size [Ref. 2: 8.2-2]. Rarely are helicopters designed by different manufacturers with the same diameter or disc loading. The industry's position is that test data cannot be accurately measured in increments of one dB. The industry has recommended that flight regimes be separated by a four and not one, dB width. From testing already completed on eight of twenty-five helicopters, (that marginally met only one or two flight profiles) it is speculated that a majority of the helicopters will be above the limit for one or more conditions. Sikorsky has predicted that if restrictive noise rules are imposed without modifications for derivative growth, one billion dollars in revenue from the S-76 will be lost to that company alone over a ten year period from 1981-1990. Depicted in Table I are the effects of an acoustic regulation on the new design helicopter market against lost revenues during this period. This table displays cost and revenue data obtained from helicopter companies and represents their best estimates of potential lost revenues from helicopter sales, if the FAA's noise rules go into effect in 1985. Lost revenue from sales of the S-76 helicopter are estimated at $1 billion during this ten year period [Ref. 2: 8.1-10]. In Chapter III, this large revenue loss will be discussed.

To date, there is no predictive analysis within reasonable accuracy for new aircraft designs to be ERTP. The greater the uncertainty a helicopter manufacturer has with noise abatement regulations on new or derivative models, the more flexible he has to be with his designs. If strict

noise regulations are imposed, designs for new helicopters may require a technology of such advanced state as to make production of the helicopter too expensive or impossible [Ref. 4: 33].

The industy has summarized its position for a valid ERTP analysis of the FAA's NPRM 79-13. In brief, the summary requested that there be noise measurements established on current helicopters. It also requested that there be a predictive capability available to the industry, with an accuracy consistent with the limits as set forth by the FAA.

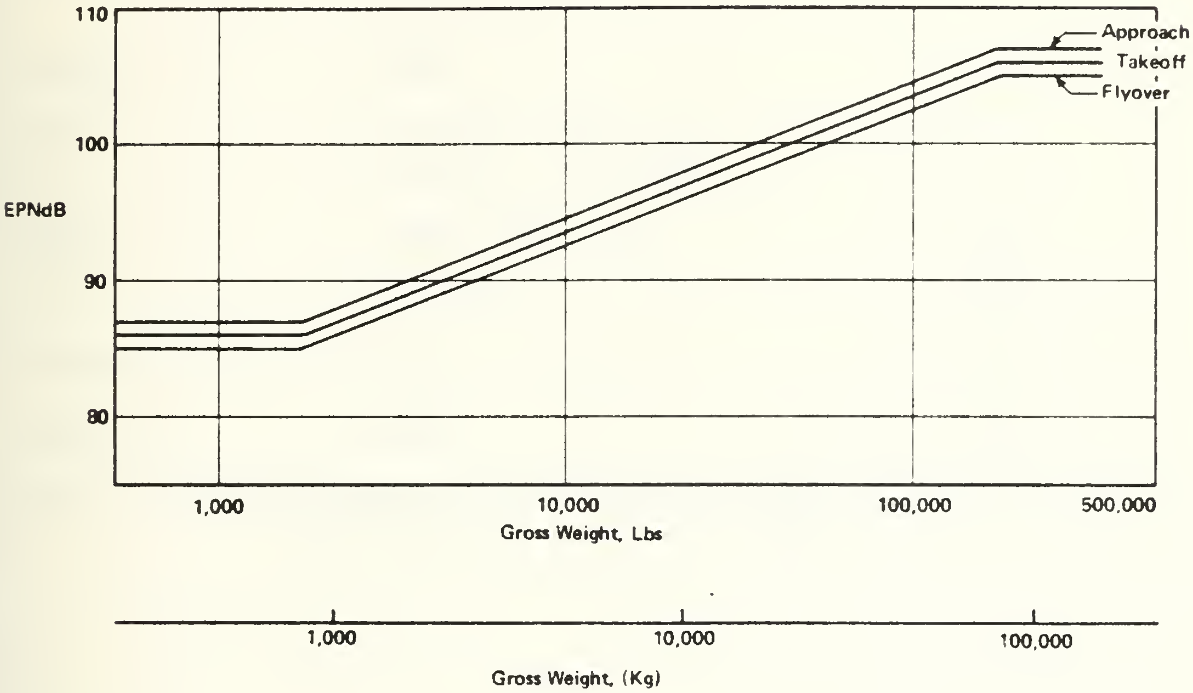
As of this writing, these requirements have not been met. Of twenty-five U.S. commercial helicopters affected only eight had fully complied with FAA measurement standards. Data for the remaining helicopters has been insufficient or nonexistent. The industry feels that all aircraft from this group should be thoroughly tested before noise rules are imposed on the industry.

The second requirement had not been met due to the inaccuracy of current predictive methods. This means that better design technology will be needed to offset uncertainties in anaylses and testings. Any uncertainties in designs will delay the introduction of new helicopters until helicopter technology catches up with design requirements.

As can be seen, noise control for helicopters is in a developmental state. Research to quiet helicopters has not been as intensively supported by the government as it was in noise control for the fixed wing industry. The helicopter industry is not prepared as of this writing to meet the strict noise limits that are proposed, without significant economic reevaluation and/or breakthroughs in helicopter aerodynamics.

In the following chapter, an economic analysis to determine cost estimates to the industry with noise regulations has been prepared. The chapter illustrates costs to

helicopter manufacturers if expensive redesigns have to be initiated to meet noise regulations. The chapter also studies what effects operating costs and price changes would have on the demand faced by the helicopter industry and users.



Formula used by the FAA to calculate noise limits.

$$105 - 10\log_{10} \frac{176,370}{\text{gr. wt}}$$

S-76 aircraft tested at a gross weight of 10,300 lbs.

TAKE OFF LIMIT	APPROACH LIMIT	FLYOVER LIMIT
93.7	94.7	92.7

Figure 2.1 Formula Used by the FAA to Calculate Noise Limits.

TABLE I

Economic Impact of Failure to Pass Production Noise Rules

COMPANY	MODELS	1981 - 1990 POTENTIAL LOST REVENUE
Aerospatiale	315, 350, 355, 365N, 332	$300M
Agusta	A-109	500M
Bell	206, 206L, 205, 212 412, 222, 214, 214ST	5400M
Boeing	234LR, 234UT, 107	343M
MBB	105, 117	100M
Sikorsky	S-76	1000M
Westland	WG-30	530M

HELICOPTER MANUFACTURERS' ECONOMIC IMPACT ASSESSMENT OF FAA PROPOSED CERTIFICATION NOISE RULES NPRM 79-13

III. ECONOMIC EVALUATION OF THE HELICOPTER INDUSTRY UNDER NPRM 79-13

A. COST ESTIMATING RELATIONSHIPS

As mentioned earlier, the S-76 was selected as a model aircraft because of its advanced technological design and popularity as an offshore oil company transport and corporate helicopter. To better understand what challenges the industry faces with noise abatement rules, a more thorough understanding of the costs involved in designing, producing, and operating a helicopter is needed.

The helicopter cost and weight data generated for this report was collected from a number of different sources. Weight data for the S-76 was collected from the Sikorsky Helicopter Plant in Stratford, Connecticut. Cost estimating relationships (CERs), were taken from Science Applications, Inc., a private contracting firm based in Los Angeles, and from a Bell/North Texas State University study conducted in 1978. Using helicopter systems weights and production quantity as independent variables, helicopter systems costs to the manufacturer can be estimated.

Accurate cost data from Sikorsky could not be obtained, due to the proprietary nature of the data. This drawback limits the study to a degree. Attempts have been made to compensate for factors influencing manufacturing costs. These factors include: 1) an accurate production quantity of S-76 aircraft manufactured by Sikorsky, 2) an inflation index to adjust prices in 1982 dollars, 3) the amortization of research and development costs, and 4) the acceptance of "learning curve" improvements in production to help reduce costs [Ref. 5: 3-8]. Learning curve theory states that as

the quantity of items produced increases, the costs associated with the production decreases.

For analysis, the S-76 was broken down into twelve subsystems as described by Dr. Michael Beltramo in his research for NASA, "Parametric Study of Helicopter Aircraft Systems Costs and Weights". These twelve areas were selected for commonality of aircraft function and correspond closely to the standard weight groups as defined in Military Standard 1374. The twelve catagories, their weights, production quantity, cost formulas, and an index to adjust Dr. Beltramo's 1978 costs into 1982 costs, are listed in Table II. A brief description of the twelve subsystems is listed below, and an explanation of how Dr. Beltramo derived his cost estimating equations is found in Appendix A, Section A.

1. Main Rotors and Head Assembly. The main rotors are composed of four titanium spars, each with a thinly swept, tapered tip to reduce stress and noise. The head assembly is a one piece aluminum hub with elastomertic bearings. Bifilar vibration absorbers to dampen blade forces and spindle assemblies join the blades to the head, and are included in this weight.

2. Tail Rotors. The tail rotors (2) are smaller in size than the main rotors, but basically include similar components.

3. Fuselage. The fuselage is the shell structure that includes doors and window frames, decking, bulkheads and windscreens.

4. Landing Gear. The S-76 uses a retractable landing gear system, which is hydraulically actuated. The landing gear structure is composed of struts, side and drag braces, wheels, brakes, and the retraction system.

5. The propulsion system. The propulsion system of the S-76 is divided into two catagories. The first catagory is the two engines that supply the power for the aircraft. These are Allison 250-C30's, that are electrically started from a battery, and employ a single stage, centrifugal compressor section. All mounts and associated hardware are included in this weight. The second catagory is the transmission and gear box assemblies. The main gear box connects the two turbo-shaft engines to the main rotor, the intermediate, and tail rotor gear boxes, plus all connecting drive shafts.

6. Flight Controls. The flight controls for the S-76 include all control rods from the cockpit to the main

rotor servos. This includes the cyclic, collective, and rudder pedal controls for a dual piloted aircraft.

7. Instruments. The instruments provide basic monitoring and warning functions for safe helicopter flight and engine operation. The basic instrument package in the S-76 includes cockpit indicators and warning lights, all associated "black boxes" for electronic signals, and monitoring devices for a dual piloted aircraft. This weight does not include instruments for flight conditions during Instrument Meteorological Conditions, (IMC), which is optional equipment.

8. Hydraulics. Hydraulic systems on a helicopter are used primarily to power the flight controls and landing gear, and on some models, cargo winches. The system includes pumps, reservoirs, accumulators, filters, valves, manifolds, and miscellaneous support equipment. The S-76 uses dual back-up, identical hydraulic systems, powered from pumps driven by the main gear box.

9. Electrical. The electrical system supplies power to the various instruments and lights within the S-76. The basic S-76 requires DC power only, that can fulfill starter and generator power. The S-76 has dual engine mounted 200 ampere starter generators, each being capable of powering all equipment should one engine fail. A seventeen ampere-hour nickel-cadmium battery is also standard equipment. There is also a connection on the helicopter for external DC power.

10. Avionics. This subsystem is one of the most technically advanced systems found in the aircraft today. Consequently, most avionics are treated as optional equipment. Depending on mission requirements and single/dual piloted aircraft, avionics equipment can become extremely expensive. The basic avionics package in the S-76 includes instruments for heading reference and aircraft attitude. The avionics package used for this study included one VHF transceiver with antenna and a cockpit/cabin intercom system. No navigational equipment was included in the weight of the avionics subsystem.

11. Furnishings and equipment. Like the avionics package designed for operator preferences, extra furnishings and equipment can become extremely expensive. Basic furnishings and equipment include seat covers, rugs, strobe lights, miscellaneous accessories such as ashtrays, and other incidentals that complete the aircraft empty weight of 5703 pounds.

12. Inhouse assembly. Inhouse assembly includes all labor by the manufacturer required to bring the major components of the helicopter into a finished product. It includes not only installation and checkout but quality control.

The twelve subsystems cover all recurring production and subcontracted costs. Additionally, these formulas can be applied to any helicopter airframe. When combined with S-76 weight and production data and totalled, they estimate the costs to Sikorsky to produce the S-76.

TABLE II

Cost Estimating Equations

SYSTEM	WEIGHT	EQUATION	COSTS ($)
Main Rotor & Head	1009	$C= -12,938+101WQ^{-.0740}$	55,669
Tail Rotors	77	$C= 102WQ^{-.0740}$	5,287
Fuselage	1531	$C= 860W^{.848}Q^{-.286}$	93,584
Landing Gear	370	$C= 84WQ^{-.2176}$	9,709
Propulsion			
a) power plant	572	$C= -17,709+1219WQ^{-.2345}$	181,285
b) drive system	953	$C= 19,946+83W\ Q^{-.0740}$	73,197
Flight Controls	245	$C= 156WQ^{-.0896}$	23,671
Instruments	62	$C= 125WQ^{-.0896}$	4,780
Hydraulics	100	$C= 91WQ^{-.0896}$	5,636
Electrical	286	$C= 143WQ^{-.0896}$	25,330
Avionics	74	$C= 6847+125WQ^{-.0896}$	12,576
Furnishing & Equip	424	$C= 69WQ^{-.0896}$	18,119
Inhouse Assembly		$C= 5.325\left[\sum_{i=1}^{11} c_i - c_j\right] Q^{-.3959}$	
		j= (4,5a,7,10)	192,658
Total Costs to Sikorsky			701,501
Deflator Index to Adjust for 1982 Prices		$\frac{1982}{1977}\quad\frac{94.4}{62.2}$	x 1.52
Total Costs 1982 Dollars			1,064,657

W=weight
Q=210

Cost Equations Borrowed from Beltramo's Study
page 3-2

B. HELICOPTER INDUSTRY'S COST ESTIMATES UNDER NOISE REGULATIONS

Derivative helicopter growth includes increases in gross weight to absorb new systems and equipment, and to increase payload and productivity. Normal growth in available helicopter power allows for the growth in gross weight, while maintaining performance. As operators of helicopters such as the S-76 become more confident in the airframe, so too does Sikorsky in its design. Derivatives can be produced with little significant structural changes. If, however, critical dynamic component systems have to be remodeled because of the noise ruling, the economic impact and associated risks shouldered by the manufacturer and users alike, would be high.

There are three major subsystems that are principal generators of noise in the helicopter. The three areas are: 1) the power plant, 2) the transmission and gear box areas, and 3) the rotors. Normal derivative growth has historically been based on production models that were profitable sellers. Derivatives are engineered from new technology that makes the aircraft fly faster, carry more cargo/passengers, and overall be more productive. Any constraints placed on normal derivative growth deprives the manufacturer of opportunities to sustain productive aircraft design life and recoup original R&D costs. Derivative models ensure long production times and the ability of the manufacturer to realize a profit on his investment. New helicopter growth cannot be launched without profits from derivative models.

Sikorsky is very concerned about the impact noise rules would have on the sales of its new airframe. To quiet the S-76 helicopter, engineers can look at the three major areas of noise as areas for redesign and modification.

The first area, the engine, is technically a problem faced by the Allison Company, since they are producers of the power plants that drive the S-76. Engine noise is primarily distributed around compressor tones, combusted fuel, and exhaust gases. Engines are designed to meet compressor and turbine speeds that will produce the energy required to power the size and weight of the aircraft. Derivative helicopters will be designed to fly faster and carry heavier loads, thus relying on engines that are stronger and more reliable, but with as little additional engine weight as possible. To meet these new requirements, an uprating of existing engine performance will be needed. Additional power estimations vary from 18-22.5%, which would increase engine shaft horsepower from 650 to 796 shp. This increase, according to engine designers, is beyond the growth potential and technology now in production [Ref. 4: 3,33].

Newer and more quiet engines will be required to drive new transmissions and gear boxes. Transmissions and gear boxes will have to be modified to accomodate the more powerful engines. Sikorsky has estimated that changes in gear box ratios and drive systems would have to be uprated from 9-11%, to stay within derivative growth and noise limits. Redesigning transmissions and gear boxes would be a very costly undertaking, since special tools and castings would have to be redesigned as well.

The area generating the greatest noise in helicopter flight is the helicopter's rotor blades. To reduce blade slap and flap, engineers have suggested several alternatives. One alternative is to decrease rotor speed. If the rotor speed is to be decreased without decreasing rotor efficiency, there has to be a corresponding increase in the lifting surface. This can be accomplished by several methods. One method is to increase the blade's chord. A second method would be to increase the number of blades.

If engineers attack the noise problem by changing the number of blades, this would require that a new mast, rotor head and assembly, and control levers be designed. When the blade tip speed is reduced, new transmission and gear box speeds are required. The interaction of many dynamic components associated with helicopter flight will eventually lead to the redesigning of not one system, but several.

The rotor system is unique in that the most dramatic technological changes have, in recent years, taken place with this component. Sikorsky uses a composite blade that reduces maintenance costs and adds a substantial life expectancy to the blade, which is currently rated at 11,750 flight hours. Each blade weighs 175 pounds and costs approximately $40,000 to Sikorsky to produce. To reduce noise through the addition of an extra blade, or from increasing the blade's chord, (to accomodate slower tip speeds without sacrificing performance) would involve redesigning several major and expensive components.

As can be seen, designing and manufacturing helicopter components is a very expensive process and involves years for development and testing. Once these ideas are transformed into components and produced, the costs involved in owning, operating, and maintaining such equipment are also affected.

C. OPERATING COSTS UNDER NPRM 79-13

Operating costs vary considerably with the type of operation, the geographical area flown in, and the annual hourly aircraft utilization. These factors affect depreciation and insurance rates, as well as maintenance costs and aircrew salaries. Direct operating costs are tangible and easily recorded. Indirect costs - or those costs associated with operation of the business not directly related to operation

of the aircraft - such as rent, utilities, training, administrative services, management and overhead, generally range from 50-200 percent of direct operating costs, depending on services provided and business operations [Ref. 6: 1]. These expenses, plus profit, should be considered by a helicopter operator when determining helicopter costs, because of their economic impact on business operations.

The cost items associated with a capital investment can be very broad and expensive. In the offshore oil exploration and drilling industry, maintaining aircraft is even more costly.

For the sake of continuity, the S-76 will be used as an example aircraft for the following breakdown of an operator's costs. When flying to the oil rigs, two pilots operate the S-76 as an additional measure of safety. Crew costs, including fringe benefits, could reach $30,000 per year, per pilot [Ref. 6: 2]. If the pilots fly 800 hours per year, this equates to crew costs of $75.00 per flight hour. Under NPRM 79-13, there would be no change in the pilot requirement, and costs to the operator would be unaffected by noise rules.

Fuel consumption by the S-76 during normal cruise conditions is approximately 600 pounds per hour or approximately ninety U.S. gallons. Jet fuel is just about as expensive as gasoline, and if calculated at $1.20 per gallon, this equals about $108.00 per hour in fuel costs. Other fuels and lubricants, such as hydraulic fluid, transmission, and gear box oils, are usually estimated at seven percent of the fuel costs. The total cost of fuel and oil to operate the S-76 per hour would be about $116.

Insurance costs to operate offshore oil helicopter services fluctuate with aircraft models, the safety features installed, pilot experience, and hours flown per year. Insurance on the aircraft itself is calculated on a four

percent flyaway price of the aircraft. Four percent is Sikorsky's estimate for fuselage damage and liability coverage. A fully equipped S-76, with instruments and safety equipment for over water flights, costs approximately $2,202,130 [Ref. 6: 2]. Four percent of this figure equals $88,085 per year, and although this figure would not be directly changed due to NPRM 79-13, aircraft that did not meet NPRM 79-13 could not be certified by the FAA and therefore insurable. Insurance rates would change, however, on any model that incorporated new engineering designs to quiet the helicopter, thereby making the aircraft more expensive to replace or fix if damaged.

Maintenance of the aircraft is one of the most expensive ongoing operating costs involved in helicopter operations. Maintenance labor rates per aircraft are explained as manhours required per flight hour of service. Skilled mechanic labor alone, exclusive of overhead, is computed on an average of $13.00 per hour, with four manhours per flight hour required for S-76 operation [Ref. 6: 3]. This equates to $52.00 for labor per flight hour. As with any new design or engineering change, mechanics must maintain their proficiency by learning new systems and maintenance techniques. There would be an additional cost to the operators in training mechanics on any new maintenance techniques that resulted from engineering redesign. Such costs would include a mechanic's time away from direct aircraft maintenance, lost flight times due to longer aircraft turnaround periods, additional purchases of special tools, technical manuals, or direct factory supervision until private companies could sustain levels where their own mechanics could handle the new techniques. The transition period associated with the introduction of a new piece of equipment, or method of maintaining a piece of equipment, would have a less costly impact on flight operations if the changes are

forseen and mechanics trained prior to actual airframe modifications.

The overhaul and/or replacement times on the major components (main, intermediate and tail rotor gear boxes, plus main rotor head assemblies) and the hydraulic systems, are based on an hourly useage rate from 1800 to 3000 flight hours, depending on aircraft system and component. As part of a contract service from Sikorsky, a parts exchange program amortizes these costs at $50.00 per flight hour [Ref. 6: 3]. It would be very difficult to evaluate the cost of overhauling new equipment designed to reduce noise, but it is a safe assumption that with the introduction of new equipment, inspections and overhaul time periods could be higher than normal.

The main and tail rotor blades would be the major components most likely affected by noise rules. A set of main blades costs $164,000 to an operator, and $48,000 for tail rotor blades. These blades have a life expectancy of 11,750 flight hours, during which time only minor rework is expected, such as replacement of the tip caps or leading edge abrasion strips. These costs are estimated at one half the initial cost of the blades, or $9.00 per flight hour, given that the blade survives its expected life cycle.

Other aircraft parts and spares, computed for an instrument equipped aircraft, are estimated at $32.00 per flight hour. This additional amount is needed to replace minor avionics equipment, cleaning fees, repair parts, and other necessary maintenance requirements. The cost to add instrument and survival equipment in the S-76 is approximately $543,830, the difference between the selling price of $2,202,130 and the basic, off-the-production line, $1,658,300.

The overhaul period for engine performance is 1500 hours of operation. Additional improvements by the Allison Company have led to increases in the hours between overhaul periods, from 1500 to 3500 hours. This will reduce operators expenses for major engine overhauls, but the operator is still faced with minor overhauls and inspections at other intervals, such as inspections at 1750 hours of the turbine and exhaust areas. For operating expenses, overhaul costs that include parts and labor, are approximated by Allison at $90.00 per flight hour [Ref. 6: 3].

If the engine has to be redesigned to meet noise limits or increases in power to drive new transmissions and drive systems, these modifications would have a proportional increase in overhaul costs and timing. Even if new engines with an increased capacity in shaft horsepower of 18 to 22.5 percent added ten percent more weight to the engine, (a rough estimate from a NASA engineer) this would increase engine costs from $181,285 to $366,276, according to Dr. Beltramo's cost equations.

The S-76 is a very modern and technologically designed aircraft. In resale market value, the S-76 is expected to retain one-half to two-thirds of its original value after ten years of service. For depreciation computations, a twenty-five percent residual value can be computed over the same time period [Ref. 6: 4]. Depreciation of the S-76 alone would then be the total cost of the airframe, $2,202,130, divided over a ten year period with a twenty-five percent residual value. This equates to a yearly depreciation value of $165,160. Any additional costs to the aircraft, to meet NPRM 79-13 standards, would increase the value of the aircraft, increasing operator's depreciation over the useful life of the aircraft.

In Table III, the direct operating costs per flight hour for operators of the S-76 are summarized [Ref. 6: 4]. It is a breakdown of all costs associated with helicopter operations as estimated before noise modifications and redesigning take place. Table IV is a projection of increased costs as a result of new designs on rotor blades, engines, and transmission areas on a derivative aircraft. It shows higher operating cost using adjusted figures from Table III and weight and cost data from Table II. The derivative figures were best estimates derived from Sikorsky publications and cost data generated from helicopter manufacturers producing commercial helicopters of similar design and weight to that of the S-76, as reported to the IACO Committee on Aircraft Noise (CAN) Working Group B, in May of 1982. Table IV is a projection of what operators may have to face in increased costs, if Sikorsky and other helicoper manufacturers have to redesign for noise abatement rules.

D. ELASTICITY EFFECT OF NOISE RULES TO MANUFACTURERS AND OPERATORS

To analyse more fully the effects noise rules would have on manufacturers and operators, it is important to understand how responsive these markets are to changes. Since new regulations would undoubtly raise manufacturers and operators' costs, these costs would in turn have to be absorbed by consumers. The important economic question here is how will helicopter operators respond to increased costs of helicopters? This question deals with demand and price elasticity and must be carefully studied to evaluate its impact on the market.

Given an increase in costs to Sikorsky, what would be their change in revenue from a decrease in sales? Revenue is related to the elasticity of demand for the product.

Elasticity is related to the presence of substitutes for the product and is defined as the percentage change in quantity divided by the percentage change in price. Unfortunately, it is difficult to measure the elasticity of sales to helicopter operators because they only purchase helicopters in order to provide services to others, just as buses are commonly produced for and purchased by bus companies. What matters is the elasticity of helicopter services to the consumers of the services as discussed in Chapter II; ie. lumber, oil, executive transportation, etc. Therefore, there are several relevant demand curves here. The substitution possibilities will be discussed below to provide some qualitative idea of the elasticity.

The elasticity of a product measures the change in prices for a change in demand. As mentioned earlier, the forestry industry uses heavy-lift helicopters to remove felled trees from remote areas otherwise unaccessible by logging trucks. The tradeoff for the companies in using helicopters is the rapidity with which helicopters can remove logs without having logging companies invest extra money constructing accessible roads for logging trucks. The lumber companies are weighing the value of faster and expensive helicopter services against slower trucks which require new roads.

Similarily, oil companies estimate the economic value of flying crews and supplies to oil rigs instead of using slower, surface vessels. The opportunity cost to fly a number of workers to oil rigs at one time is lower because crews can be changed in a fraction of the time it would take ships to complete the transfer. For example, if an oil rig is located sixty miles offshore, it could be serviced by an S-76 helicopter carrying twelve passengers in about thirty minutes. The round trip would last about one hour at a cost of $1000. A surface vessel making twenty knots and carrying

twelve passengers would make the round trip in about six hours. If the cost to operate the surface vessel is only $100 per hour, this would equal a $600 cost, but the trip has taken a longer period of time, with a high loss in production for the crews and the oil company. A three hour transit for twelve passengers at, for example, $15.00 an hour, equals $540 in wages lost from production. Total costs for the movement of crews by surface ship equals $1140. On the other hand, the helicopter cost $1000 per hour plus the lost wages for twelve passengers (at the same wage scale) for thirty minutes, or $90.00, for a total cost to the company in rental and lost production of $1090.

This simple example demonstrates the savings oil companies enjoy from utilizing helicopters instead of slower, surface ships.

There is also a large demand for executive and commuter helicopter services. In this environment, transit times between business districts and airports can be shortened by using helicopters as shuttles. Intercity services via helicopters have been introduced in several areas within the United States, the most extensive being the San Jose, Oakland, and San Francisco commuter routes. As helicopter costs rise, the more likely executives will take ground transportation, which is much cheaper. Usually, only a few executives travel together, so even though their salaries are higher, there is likely to be more substitution than in the oil example.

When noise abatement regualtions for the helicopter industry eventually become law and manufacturers are required to engineer their helicopters to be more quiet, what will be the burden of these changes? The answer to this question will depend upon a number of factors. First, how responsive to a price change are helicopter operators? That is, if manufacturers increase their prices on

helicopters and pass this increase onto users, will users look elsewhere for other means of transportation? If consumers of helicopter services do not respond to increases passed on to them, then market demand for helicopters as a means of transportation is said to be inelastic and unresponsive to price increases. But, if a price rise is passed to operators and they stop purchasing helicopters as their customers turn elsewhere for substitutes, then the demand for helicopters becomes elastic. This is the operator's signal to the manufacturer that helicopter operations have become too expensive and alternative means of transportation have been found by the ultimate consumer.

The impact of these higher costs to operators and customers can be reflected in a number of ways. If customers can find cheaper substitutes than helicopters, then increased costs will drive them to substitutes. Operators must determine how far on a customer's demand curve he can raise prices before customers search for alternatives. Because each catagory of customer has its own demand curve, the elasticity for helicopters usage varies and is difficult to estimate. If customers cannot find substitutes that give them as much utility as helicopters, even with the extra costs, then customers will elect to absorb these costs.

Graphically, the costs effects of noise control regulations in the form of increased expenses are displayed in Figure 3.1. The initial market equilibrium is at E, with the quantity sold, 210 units. This was about Sikorsky's annual S-76 production. The price of each S-76 to the operator was estimated at $2.2 million. An approximate 22% increase (as estimated by Sikorsky in their report to the Economics Subgroup of the IACO Committee in May, 1982) would increase this cost to $2.63 million [Ref. 4: 33]. If regulations increase costs to the manufacturer by 22% per

aircraft, what might be the effect on the number of aircraft sold? Two hundred ten helicopters at $2.2 million approximates a $462 million business annually. If S-76 sales were to slip by fifty-seven aircraft per year, this would be reflected in a $125.4 million annual loss. Extending this annual loss through the relevant time period, 1981-1990, (like Sikorsky has predicted in Table I) then a $1 billion loss in S-76 sales could be realized. The drop in sales from 210 to 153 aircraft reflects an annual decrease of twenty-five percent, and is characterized by $\frac{\Delta Q}{Q}$ =.25. The market elasticity, (given $\frac{\Delta P}{P}$ =.22) of $\frac{\Delta Q}{Q} \div \frac{\Delta P}{P} = \frac{.25}{.22}$ = 1.136 indicates that Sikorsky's estimate of a $1 billion loss in reasonable, since this is a relatively low elasticity.

From my talks with marketing analysts at Sikorsky they tend to agree with this approach to helicopter sales. They feel that the initial cost of a helicopter to a user is not the most important economic consideration facing a user. The initial outlay for the purchase of a helicopter is tied to the cost of borrowing money. The major economic problem facing operators is the return operators expect to receive from helicopter operations. The cost of helicopter utilization to the operator, according to Sikorsky, should be one-half to two-thirds of his gross revenues. Annually, operators try to meet in gross revenues the purchase price of their helicopters. From Table III, the operating expenses per hour for S-76 usage has been costed at $789 for 1000 hours of flight time. At this rate, operators should be charging (at one-half) $1184 to (at two-thirds) $1318 to customers per flight hour if they expect to reach this revenue objective. These figures represent a high hourly cost for helicopter operations, but the utility and diversification of helicopters have made them indespensible modes of transportation.

There are several lessons to be learned from demand and price elasticity. Marketing predictions have to be extremely accurate when they forcast market reactions to price changes. Care must be followed to read clearly signals given by users as to whether or not operators would accept increases in helicopter costs. If these market signals are misinterpreted, manufacturers could wind up bearing the entire burden of increased costs.

TABLE III

Summary of Direct Operating Costs per Flight Hour

	ANNUAL UTILIZATION - HOURS			
FLIGHT OPERATIONS	1000	1400	1800	2200
Crew Costs	75.00	75.00	75.00	75.00
Fuel and Oils	96.30	96.30	96.30	96.30
Insurance	88.09	62.92	48.94	40.04
Total Flt Operations	259.39	234.22	220.24	211.34
MAINTENANCE				
Labor	52.00	52.00	52.00	52.00
Overhauls	50.00	50.00	50.00	50.00
Rotor Blades	9.00	9.00	9.00	9.00
Parts & Repair	32.00	32.00	32.00	32.00
Engines	90.00	90.00	90.00	90.00
Total Maintenance	233.00	233.00	233.00	233.00
DEPRECIATION	165.16	117.97	91.76	75.07
OVERHEAD	131.71	117.04	109.00	103.88
TOTAL ESTIMATED DIRECT COST OF OPERATION	789.26	702.23	654.24	623.29

TABLE IV

Comparison of S-76 Costs Before and After NPRM 79-13

	BASELINE/1000hrs	DERIVATIVE	%CHANGE
Unit Costs ($)	2,203,130	2,643,556	20
Operating Costs			
a) crew	75.00	75.00	-
b) fuel & oil	96.30	97.26	1
c) insurance	88.09	88.97	6
d) depreciation	165.16	198.27	20
e) maintenance	233.00	257.40	10
f) spares	32.00	47.00	46
Overhead	131.71	152.78	9
Total Hourly Operating Costs	789.26	916.68	16

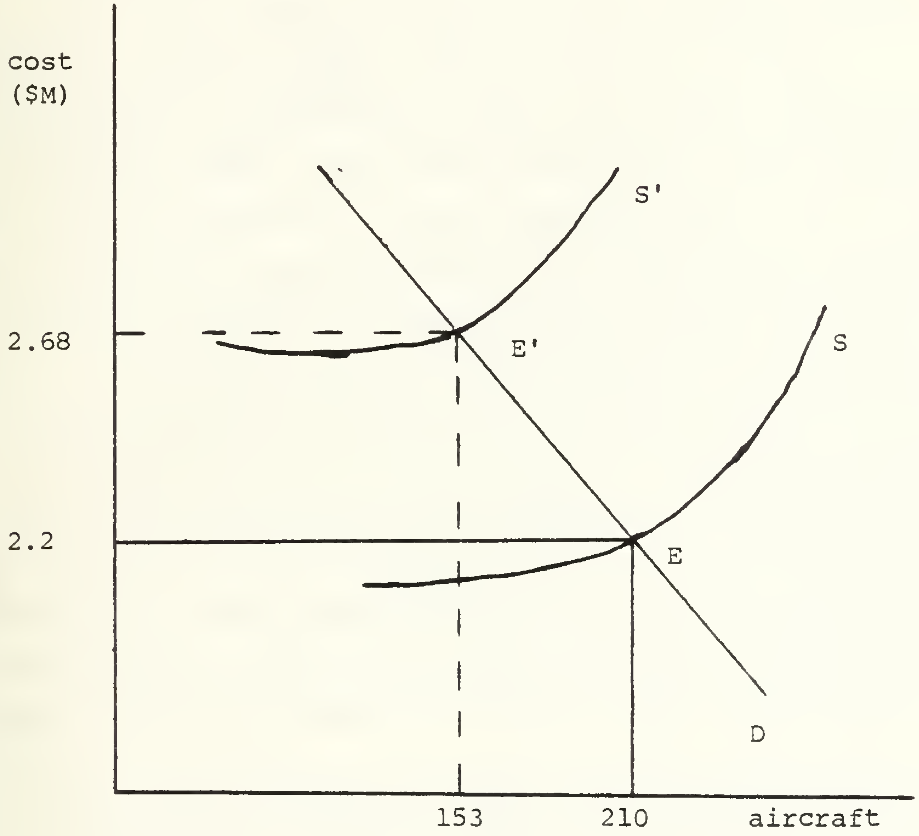


Figure 3.1 Price and Demand Elasticities.

APPENDIX A

A COMPARISON FOR ESTIMATING HELICOPTER PRODUCTION COSTS

A. THE BELTRAMO STUDY

The Beltramo study, conducted from 1978-80, was a study sponsored by the National Aeronautics and Space Administration to determine recurring weight estimating relationships (WERs) and cost estimating relationships (CERs) for helicopters at the systems level. Dr. Beltramo's weight estimating relationships were developed through statistical analyses. He examined helicopter subsystems' weights to determine their relationships to design and performance characteristics. Dr. Beltramo found that most helicopter subsystem's weights could be accurately evaluated using one or two performance variables, which best describe the functional and statistical qualities of the system. Once accurate weight estimating relationship formulas had been derived, Dr. Beltramo could use this weight and production quantity as parameters for his cost estimating equations.

Dr. Beltramo's WERs and CERs were developed using cost and performance data he had gathered from manufacturers, the Department of Defense, and subcontractors. Although he based some of his CERs on inhouse production and others on subcontracted costs, this did not significantly alter his overall cost estimates. By using cost data from one supplier in the industry, Dr. Beltramo produced CERs that gave reasonable estimates eventhough they were based on heuristic rather than statistical reasoning. Dr. Beltramo also assigned confidence values to his data to indicate how reliable he estimated his sources, and to help users of his equations recognize areas where errors may arise.

CERs are useful to manufacturers in that they can more accurately predict recurring production costs and their impact on alternative designs, labor, materials used, and technology. Unlike his weight data, Dr. Beltramo's cost data had to be adjusted for cost elements applicable to some of his twelve systems and not others [Ref. 5: 3-8]. Examples of such elements are the cost of research and development, engineering, and tooling. These costs had to be amortized over certain production areas and not others. Other indirect cost elements that had to be considered were learning curve adjustments and inflation.

The Beltramo study included all costs to the manufacturer for inhouse production, subcontracted costs, and inhouse assembly costs. Inhouse production elements included: fabrication, engineering, tooling and raw materials. Costs that were subcontracted were for outside production and purchased equipment. Inhouse assembly costs included: quality control, minor and major assembly, and were handled by a separate equation. Here, Dr. Beltramo subtracted from the manufacturer's total cost items that were subcontracted. The items not produced at a manufacturer's plant (such as aircraft engines, certain avionics equipment, and landing gear), do not represent a production cost to the manufacturer, but an assembly cost, that when added to production, give the total cost of a helicopter to the manufacturer.

The Beltramo study was an indepth study to cost out the helicopter by subsystems. His work has proven to be of value to NASA and other engineers working with design parameters of weight and performance when costs were not known and had to be estimated.

B. THE BELL/NORTH TEXAS STATE STUDY

In 1978, a research student at North Texas State, Charles F. Bimmerle, worked in conjunction with Bell Helicopter's engineer, Johnny J. Gilliland, to develop a statistical model that would accurately estimate the recurring costs of five major subsystems comprising a helicopter. The study was conducted to show that a manufacturer's recurring costs could be statistically evaluated using production quantity, weights, and performance variables. Statistical parametric analysis had become popular and was a derivative of various cost approaches used within the Department of Defense for the past twenty-five years.

The Bell/NTS study did not attempt to analyse the total recurring costs of helicopter production to manufacturers. Rather, it was a statistical evaluation to help engineers more accurately predict costs from design parameters. The study analysed the major subsystems from which sufficient technical data was available. Five subsystems were evaluated - the airframe, (excluding the landing gear, a nonrecurring cost item subcontracted out by Bell) rotors, drive system, power plants, (excluding the engines) and electrical. The Bell/NTS study estimated that with these five catagories, eighty-nine percent of a helicopter's total recurring costs were involved [Ref. 7: 10]. The study is important in that it will give an alternative costing approach to the equations developed by Dr. Beltramo. Comparing the two studies will help analyse: 1) what parameters the developers believed to be crucial, 2) how these factors were integrated into system's analyses, and 3) a comparison of the results with a critical evaluation.

Accurate cost estimations for aircraft subsystems are important and necessary for manufacturers to know for a number of reasons. Accurate costs will help the

manufacturer determine whether or not their product will be economical to produce. Production costs will help the marketing department determine pricing policies and anticipated consumer demand.

According to the authors, the cost data generated from this study was compared against the average costs of helicopters during several production runs. Cost flucutations between the Bell/NTS study and actual production costs were slight, varying between three to five percent above or below actual costs.

The physical and performance variables considered in the study were: weight, size, speed, range, thrust, torque, RPM, and the quantity of aircraft produced. This last parameter was used as a benchmark for learning curve improvements. Table V illustrates the five major subsystems used in the Bell/NTS study, and a description of the variables used.

C. COMPARING THE TWO STUDIES

The findings from the two studies revealed cost estimations that have been analysed differently but draw close estimations in three catagories - the airframe, rotor, and electrical systems.

In comparison with the Beltramo model, a cost breakdown of these five subsystems accounted for sixty-six percent of the recurring costs to Sikorsky. ($335,059 divided by $510,507). The $510,507 figure is derived by subtracting the cost of the engines to Sikorsky, $181,285, and the cost of the landing gear, $9707, from the total cost, $701,501. The $335,059 is a total of the five subsystems from Dr. Beltramo's study as indicated in Table V.

When the Bell/NTS study analysed the electrical subsystem, they used performance and quantity variables. However, the two studies' formulas revealed very close cost

TABLE V

Cost Estimating Equations from the Bell/NTS Study

	BELL/NTS	BELTRAMO
AIRFRAME SUBSYSTEM		
$A= 6932.34xQ^{-.20248}MGWT^{.85684}ROC^{.67466}CEIL^{-.57836}RPM^{-.29455}$	246,870	236,197[1]
ROTOR SUBSYSTEM		
$R= 136.4489xQ^{-.1217}RWT^{.95723}$	57,316	60,956
DRIVE SUBSYSTEM		
$D= .003544xQ^{-.12227}HP^{.3793}RPM^{.95752}VT^{1.10141}TECH^{-.46598}$	1,764	73,197
PROPULSION SUBSYSTEM		
$P= 2956.038xQ^{-.11696}PWT^{1.61657}VOL^{-.82732}NE^{.58026}TECH^{-.45546}$	6,596	181,285
ELECTRICAL SUBSYSTEM		
$E= 30.514xQ^{-.08139}ROC^{-.60499}HP^{.78978}RPM^{.71886}$	37,827	37,906[2]

where:

Q= unit quanity (210 units)
MGWT= max gross wt. (10,300 lbs)
ROC= rate of climb (1350 ft/min)
CEIL= service ceiling (15,000 ft)
RPM= takeoff max engine RPM (6016 rpm)
RWT= rotor subsystm wt. (1089 lbs)
HP= takeoff horsepower (1300 shp total)
VT= main rotor tip speed (293 rpm)
TECH= technological factor (year 1979)
PWT= propulsion subsystem wt. (exclud. engines 97 lbs)
VOL= airframe volume (1083 cubic ft.)
NE= number of engines (2)

1. AIRFRAME SUBSYSTEM COSTS (Beltramo)

Fuselage	93,584
Flt Controls	23,671
Instruments	4,780
Hydraulics	5,636
Furn/Equip	18,119
Inhouse Ass	90,407
Total	236,197

2. ELECTRICAL SUBSYSTEM

Electrical	25,330
Avionics	12,576
Total	37,906

estimations, once the avionics costs from the Beltramo model was added to its electrical costs.

In the rotor system, the cost estimations from the two studies were once again very close, $57,316 for the Bell/NTS and $60,956 for Dr. Beltramo. Each study used production quantity and weight as their dependent and independent variables, thereby keeping the parameters consistent. One possible explanation for the differences in prices could be that Bell used a model helicopter that had had a large and successful production run. This factor could lower manufacturing costs as learning curve theory took effect. Bell could also have enjoyed discounts from larger purchases of raw materials. Additionally, technology on the Bell products was older than that used on the newer, S-76 model.

Comparing the airframe subsection from the Bell/NTS study or to the Beltramo study is more difficult for several reasons. First, the Bell/NTS study used aircraft gross weight and several performance variables in its calculations, whereas the Beltramo study used only subsystem weight and production quantity. The Bell/NTS study took more performance variables into consideration, which could have added costing error or costing not associated with airframe production as a subsystem. On the other hand, these factors may have been necessary to adequately explain the high degree of technology associated with this complicated system. To bring the Beltramo cost model into a comparative range with the Bell/NTS study, several airframe related subsystems' costs were added to the airframe cost. These related costs, (flight controls, instruments, hydraulics, furnishing and equipment, and inhouse assembly) are oriented more towards performance variables and bring the Beltramo costs closer in line with the Bell/NTS study.

Perhaps the greatest surprise noticed when comparing the two studies arose in the Bell/NTS cost analysis of the drive system. The drive system, as stated earlier, is a very complex and expensive subsystem of any helicopter. Consequently, the very low cost figure associated with the Bell/NTS study causes concern. The performance parameters that the study used seem to correlate well with drive train and engine performance - ie. horsepower, RPM, rotor tip speed, and technology, but the low cost figure derived from this formula could not represent the cost of such a major subsystem to the manufacturer.

The propulsion subsystem's estimates of the Bell/NTS study did not include costing for the power plants themselves. The reason for this is that engines for the Bell and Sikorsky helicopters are purchased from outside manufacturers and represent a subcontracting cost, not a production cost.

The drive and propulsion subsystems were included but not compared by the Beltramo model for two reasons. First, when comparing the costs between the two equations, such a large divergence resulted that a comparison was unrealistic. Secondly, the Bell/NTS study eliminated the cost of the engines and costed out instead that part of the fuselage that supports the engines (the nacelles). For the Beltramo study, engine nacelle weight was included in the weight of the fuselage. It was further assumed that the Bell/NTS study included in its breakdown of the five major subsystems costs for inhouse assembly. Since Bell estimated that these five subsystems accounted for eighty-nine percent of the recurring costs, inhouse assembly is assumed to be computed in each formula.

D. CONCLUSIONS

The Bell/NTS study was an attempt to broaden costing parameters by incorporating performance, weight, and quantity data to helicopter subsystems. In three of the Bell/NTS's subsystems, the estimating equations drew close estimates to the Beltramo model. In the remaining two subsystems, results from the cost equations from the Bell/NTS study could not be generated with a reasonable amount of confidence. This was from the fact that many of the parameters used by the Bell/NTS study were performance parameters, that added a degree of complexity to the weight-to-cost estimates. In Bell/NTS's attempt to quantify costs too accurately, they may have mislead themselves with extraneous variables that only complicated their data.

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